

## **SENSING APPARATUS FOR BLOWN FUSE OF RECTIFYING WHEEL AND ASSOCIATED METHODS**

### **Field of the Invention**

**[0001]** The present invention relates to electrical power generation, and, more particularly, to detecting conditions of a rectifying wheel for a power generator and related methods.

### **Background of the Invention**

**[0002]** A typical power generator includes a shaft and a rotor carried by the shaft. Surrounding the generator rotor is a generator stator. A turbine, such as a gas combustion turbine, a water-driven turbine, or steam-driven turbine rotates the shaft. The generator rotor is supplied DC power typically from an exciter also driven by the shaft. As the generator rotor is turned within the generator stator, electrical power is produced and is delivered to the utility power grid.

**[0003]** The exciter typically includes an exciter rotor carried by a shaft connected to the generator shaft. An exciter stator surrounds exciter rotor. Regulated DC power is supplied to the exciter stator so that AC power is

produced by the exciter rotor as the exciter rotor is rotated within the field produced by the exciter stator.

**[0004]** A rotating rectifier wheel, also called a diode wheel, is carried by the shaft of the exciter and converts the AC power from the exciter rotor into DC power that, in turn, is supplied to the generator rotor. A typical rectifying wheel includes a rotating base and a plurality of diodes carried by the base. A plurality of parallel connected diodes are typically provided for each phase of a multiphase exciter. A fuse is typically connected in series with each diode so that if the diode short-circuits, the fuse can isolate the defective diode. When sufficient redundancy is provided in the form of multiple diodes and fuses for each phase, one or more diodes or fuses may fail and the rectifier can still be operated. The exciter can be taken out of service and the defective components repaired at a more convenient time.

**[0005]** A typical approach to determining whether any of the fuses has blown is to visually inspect the rotating rectifying wheel while it is in service by using a stroboscope aimed into the exciter housing. A typical fuse may include a pop-out indicator that extends outwardly from the fuse housing when the fuse has failed. An example of such a fuse is disclosed in U.S. Patent No. 6,256,183 B1 to Mosesian. Unfortunately, this approach requires careful visual inspection on a regular basis.

**[0006]** A similar approach to determine a fuse failure while the rectifying wheel is in service is disclosed in U.S. Patent No. 3,030,551 to Lessman. This patent discloses a light connected to glow when the corresponding fuse has blown. Unfortunately, this approach also requires visual inspection using a stroboscope. Similarly, U.S. Patent No. 3,866,196 to Mann et al. discloses a blown fuse indicator including a projectile that is normally held against movement and is released when the fuse blows. It can then be observed using a stroboscope as described above.

**[0007]** U.S. Patent No. 4,164,705 to Whitney et al. discloses sensing current in the salient poles of the exciter stator. Variations in the sensed

current can indicate a number of abnormal conditions, such as whether a fuse has blown.

**[0008]** U.S. Patent No. 4,349,813 to Ishibashi et al. discloses a current transformer coupled between the fuse and diode. Voltage pulses induced by the secondary winding are received by a pulse extinction detection circuit. When the pulses are not detected, the pulse extinction detection circuit produces a DC signal. Along these lines, U.S. Patent No. 4,635,044 to South discloses an apparatus for remote sensing of a failed fuse by sensing a current flow through each fuse. The operation of the current sensors is coordinated to the rotation of the wheel by an angle position oscillator that produces a constant stream of pulses at a preselected rate. Further, U.S. Patent No. 6,466,032 B2 to Klaar discloses sensing electromagnetic pulses produced during the disconnection of the fuse by receiving the pulses at a station antenna. An encoder is also provided to determine the angular position of the rotating wheel.

**[0009]** U.S. Patent No. 4,952,915 to Jenkins et al. discloses light emitting diode detectors carried by the rotating wheel being grouped to display concentric circles of light while operating. Stationary sensors are also provided to sense the LEDs, and the LEDs are connected so that if a fuse fails, the LED is lit. No synchronization is required between the detection circuit and the rotation of the rectifier wheel to thereby simplify construction and operation.

**[0010]** Despite continuing efforts to determine when a fuse of a rectifying wheel is blown, there still exists a need for a more reliable and effective system and method.

### **Summary of the Invention**

**[0011]** In view of the foregoing background, it is therefore an object of the present invention to provide a rectifying wheel and associated apparatus for more readily and effectively sensing whether any fuses are blown.

**[0012]** These and other objects, features and advantages in accordance with the present invention by a blown fuse proximity sensing apparatus for use with a rectifying wheel. More particularly, the rectifying wheel may comprise a plurality of rectifying diodes and a plurality of fuses associated therewith. Each fuse may include a housing, a fuse element carried by the housing, and a pop-out indicator movable between a normal position and a popped-out position. In the popped-out position, the indicator extends outwardly from the housing responsive to failure of the fuse element to thereby indicate a blown fuse. The sensing apparatus may include at least one stationary proximity sensor mounted adjacent the rectifying wheel for sensing positions of the pop-out indicators without contact therewith during rotation of the rectifying wheel to thereby sense a blown fuse. Accordingly, proper operation of the rectifying wheel may be readily and accurately monitored while the electrical apparatus, such as the brushless exciter, remains in service.

**[0013]** The sensing apparatus may also include a local display, and a controller connected to the stationary proximity sensor for generating an indication of a blown fuse on the local display. The controller may also generate at least one remote output, such as to be monitored by other plant control equipment.

**[0014]** The plurality of fuses may be connected in respective groups of fuses for each phase. The controller may advantageously determine multiple blown fuses for each given phase. In addition, the controller may generate an alarm indication based upon a predetermined number of blown fuses for each given phase. In other words, an alarm may be given when multiple fuse failures indicate that corrective maintenance is needed.

**[0015]** In some embodiments, the controller may determine multiple blown fuses for each given phase without angular position sensing of the rectifying wheel. This simplifies construction and operation of the sensing apparatus. In other embodiments, the angular position may be sensed.

**[0016]** The stationary proximity sensor may comprise a magnetic proximity sensor. In yet other embodiments, the proximity sensor may

comprise one or more of an optical proximity sensor, an electric field proximity sensor, an ultrasonic proximity sensor, and an infrared proximity sensor

**[0017]** A method aspect of the invention is directed to sensing at least one blown fuse of a rectifying wheel as described herein. The method may comprise mounting at least one stationary proximity sensor adjacent the rectifying wheel for sensing positions of the pop-out indicators without contact therewith during rotation of the rectifying wheel to thereby sense at least one blown fuse.

### **Brief Description of the Drawings**

**[0018]** FIG. 1 is a schematic diagram of an exciter and generator including a blown fuse sensing apparatus in accordance with the present invention.

**[0019]** FIG. 2 is a more detailed schematic block diagram of the blown fuse sensing apparatus as shown in FIG. 1, and showing a portion of a fuse of the rectifier wheel being sensed.

**[0020]** FIG. 3 is a schematic diagram of signals processed from the blown fuse sensing apparatus as shown in FIG. 2.

**[0021]** FIG. 4 is an alternate embodiment of the blown fuse sensing apparatus as shown in FIG. 2, and showing a portion of a fuse of the rectifier wheel being sensed.

**[0022]** FIG. 5 is a schematic diagram of signals processed from the blown fuse sensing apparatus as shown in FIG. 4.

### **Detailed Description of the Preferred Embodiments**

**[0023]** The present invention will now be described more fully hereinafter with reference to the accompanying drawings in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the illustrated embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully

convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout and prime notation is used to indicate similar elements in alternate embodiments.

**[0024]** Referring initially to FIG. 1, the electrical apparatus **20** including the blown fuse sensing apparatus **40** in accordance with the invention is now described. The electrical apparatus **20** illustratively includes a generator **21** and an exciter **31** connected thereto. More particularly, the generator **21** includes a generator rotor **22** and generator stator **23** surrounding the rotor. The generator rotor **21** is driven by a turbine **25**. The turbine **25** may be a steam turbine, gas turbine, or water turbine as will be appreciated by those skilled in the art.

**[0025]** The first shaft **24** is coupled via a coupling **26** to a second shaft **34**. This second shaft **34** supports the exciter rotor **32**. The exciter rotor **32** is surrounded by an exciter stator **33**. A rectifying wheel **37** is also carried by the second shaft **34**.

**[0026]** The rectifying wheel **37** carries a plurality of semiconductor diodes **38** for rectifying the AC power created by the exciter into DC power for energizing the generator rotor **22** as will be appreciated by those skilled in the art. The diodes **38**, in turn, are protected by respective fuses **42** as will be described in greater detail below.

**[0027]** The electrical apparatus **20** also includes a blown fuse sensing apparatus **40** for sensing when at least one fuse **42** on the rectifying wheel **37** has blown. As will be understood by those of skill in the art, electrical surges and/or heat and vibration may cause a diode **38** and/or fuse **42** to fail. The fuses **42** protect the equipment should a diode **38** become short-circuited, for example. Occasionally, the fuses **42** themselves may fail irrespective of a failure of the associated diode **38**. Most exciters **31** will include a group of diodes **38** and associated fuses **42** for each electrical phase. Accordingly, the exciter **31** can still operate even with some of the fuses **42** blown.

**[0028]** In accordance with the present invention, each fuse **42** includes a pop-out indicator for indicating that the fuse is blown as described in greater

detail below. The sensing apparatus **40** illustratively includes a stationary proximity sensor **44** mounted adjacent the rectifying wheel **37** for sensing positions of the pop-out indicators without contact therewith during rotation of the rectifying wheel to thereby sense at least one blown fuse **42**. Of course, more than one proximity sensor **44** may be used in other embodiments.

**[0029]** The sensing apparatus **40** also includes a local display/controller **45** adjacent the exciter **31** for providing an operator with a local indication of the status of the fuses **42**. This local display/controller **45** may also interface to remote plant control equipment **46** as will be appreciated by those of skill in the art, such as for display at an operator's control station, for example.

**[0030]** The proximity sensing provided by the blown fuse sensing apparatus **40** permits readily and accurately determining the status of the fuses **42** of the rectifying wheel **37** of the exciter **31** for the generator **21**. Those of skill in the art will appreciate that the blown fuse sensing apparatus **40** can be used in other electrical system applications as well.

**[0031]** Turning now additionally to FIGS. 2 and 3, the blown fuse sensing apparatus **40** is now described in greater detail. As noted above, the rectifying wheel **37** includes a rotating base **39**, a plurality of rectifying diodes **38** carried by the base, and a plurality of fuses **42** carried by the base and associated with respective diodes. Only a single diode **38** and single fuse **42** are shown in FIG. 2 for clarity of explanation. The fuse **42** illustratively includes a casing or housing **51**, an internal fuse element **52** within the housing, and a pop-out indicator **54** movable between a normal position and a popped-out position. In the popped-out position the indicator **54** may extend outwardly from the housing about one-half an inch, for example. In the popped-out position, the indicator **54** extends outwardly from the housing **51** responsive to failure of the fuse element **52** to thereby indicate that the fuse has blown.

**[0032]** The housing **51** includes a tubular body **59** and a pair of spaced apart end electrodes or ferrules **55a**, **55b** connected thereto. An insulating

material, such as sand, for example, surrounds the fuse element **52** and fills the interior of the housing **51** as will be appreciated by those skilled in the art.

**[0033]** The fuse **42** with the pop-out indicator **54** may be of the type as offered by Ferraz Shawmut Inc. that has a North American Headquarters in Newburyport, Massachusetts. The pop-out indicator **54** may include a spring biased member **56** that is released by a meltable element **58** connected in parallel with the fuse element **52**. U.S. Patent No. 6,256,183 B1 to Mosesian discloses such a fuse and is incorporated herein by reference in its entirety.

**[0034]** The local display/controller **45** includes the local display **61** and a controller **68** connected thereto. Both may be contained within a common housing **59**. The controller **68** is connected to the stationary proximity sensor **44** and illustratively includes a processor **60** and a display driver **66** connected thereto for generating an indication of a blown fuse **42** on the local display **61**. The controller **68** also illustratively includes a memory **64** connected to the processor **60** although in some embodiments the memory may be embedded with the processor as will be appreciated by those skilled in the art.

**[0035]** The controller **68** also includes a local input device **63**, such as a keyboard or series of switches, for example, for permitting selection of various operating parameters. The controller **68** also includes sensor input/output circuitry **62** for electrically interfacing the processor **60** to the proximity sensor **44**. In addition, the controller **68** also illustratively includes a remote input/output circuit **65** for interfacing the processor **60** to downstream circuitry, such as the remote display and controller **46** (FIG. 1). This remote I/O circuitry **65** may provide dry relay contact outputs and/or a serial or data communications bus interface, for example.

**[0036]** The plurality of fuses **42** may be electrically connected in respective groups of fuses for each phase. The groups of fuses **42** may be physically arranged in a pattern about the rectifying wheel **37**, such as ABC ABC..., for example. The controller **68** may advantageously determine multiple blown fuses for each given phase. The controller **68** may generate an alarm indication based upon a predetermined number of blown fuses for each

given phase. In other words, an alarm may be given when multiple fuse failures indicate that corrective maintenance is needed.

**[0037]** The stationary proximity sensor **44** may comprise a magnetic proximity sensor. In yet other embodiments, the proximity sensor may comprise one or more of an optical proximity sensor, an electric field proximity sensor, an ultrasonic proximity sensor, and an infrared proximity sensor. Proximity sensing of the pop-out indicator **54** using such sensors provides a very reliable and simple approach to determine whether a fuse **42** is blown.

**[0038]** As understood with reference to FIG. 3, at a first time  $t_1$ , none of the fuses **42** are blown in accordance with a hypothetical example of operation of the sensing apparatus **40**. At time  $t_2$ , a fuse is detected as a blown fuse as indicated by the spike at position 2. Later, at time  $t_3$ , another fuse is detected as being blown and this fuse is at position 9. Thereafter at time  $t_4$ , yet another fuse is indicated at being blown at position 12. Since two fuses, at positions 9 and 12, are now indicated as being blown, and since these are known to be in the same phase because of a phase pattern of ABC ABC..., an alarm may be generated so that the rectifying wheel **37** can be taken out of service and the blown fuses replaced. Of course, the alarm threshold could be set for other numbers of fuses in each phase, and/or a total number of fuses irrespective of the phases. Of interest, it is not necessary to sense the absolute angular position of the rectifying wheel **37** to know that multiple fuses in the same phase are blown as will be appreciated by those skilled in the art. This simplifies construction and operation of the sensing apparatus **40**.

**[0039]** Turning now additionally to FIGS. 4 and 5, another embodiment of the sensing apparatus **40'** is now described. In this embodiment, the sensing apparatus **40'** also includes a marker **71** on the rectifying wheel **37'** and an angular position encoder or sensor **70** cooperating with the marker to determine an absolute angular position of the rectifying wheel **37'**. The output of the position encoder **70** is coupled to the controller **68'** via the sensor I/O circuitry **62'**. Accordingly, the controller **68'** can determine which fuse in which phase is blown. Those other elements of the apparatus **40'** are indicated with

prime notation and are similar to those described above with reference to the apparatus **40** described above with reference to FIG. 2. These other elements need no further discussion herein.

**[0040]** As shown in FIG. 5, the controller **68'** can determine which fuse in which phase is blown. At time t1, no fuse in any phase is blown. At time t2, the number one fuse in the B phase is blown. At time t3, another fuse, the third fuse in the C phase is blown. At time t4, the fourth fuse in the C phase is determined as blown, and an appropriate alarm may be generated to indicate a need for corrective maintenance.

**[0041]** A method aspect of the invention is directed to sensing at least one blown fuse **42** of a rectifying wheel **37** as described herein. The method may comprise mounting at least one stationary proximity sensor **44** adjacent the rectifying wheel for sensing positions of the pop-out indicators **54** without contact therewith during rotation of the rectifying wheel to thereby sense at least one blown fuse. Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Accordingly, it is understood that the invention is not to be limited to the embodiments disclosed, and that other modifications and embodiments are intended to be included within the spirit and scope of the appended claims.